Stabilization and racetrack application of asymmetric Néel skyrmions in hybrid nanostructures

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ABSTRACT

Magnetic skyrmions, topological quasiparticles, are small stable magnetic textures that possess intriguing properties and potential for data storage applications. Hybrid nanostructures comprised of skyrmions and soft magnetic material can offer additional advantages for developing skyrmion-based spintronic and magnonic devices. We show that a Néel-type skyrmion confined within a nanodot placed on top of a ferromagnetic in-plane magnetized stripe produces a unique and compelling platform for exploring the mutual coupling between magnetization textures. The skyrmion induces an imprint upon the stripe, which, in turn, asymmetrically squeezes the skyrmion in the dot, increasing their size and the range of skyrmion stability at small values of Dzyaloshinskii−Moriya interaction, as well as introducing skyrmion bi-stability. Finally, by utilizing the properties of the skyrmion in a hybrid system, we demonstrate free from the Hall effect and unlimited skyrmion transport along the racetrack.

Supplemental Material

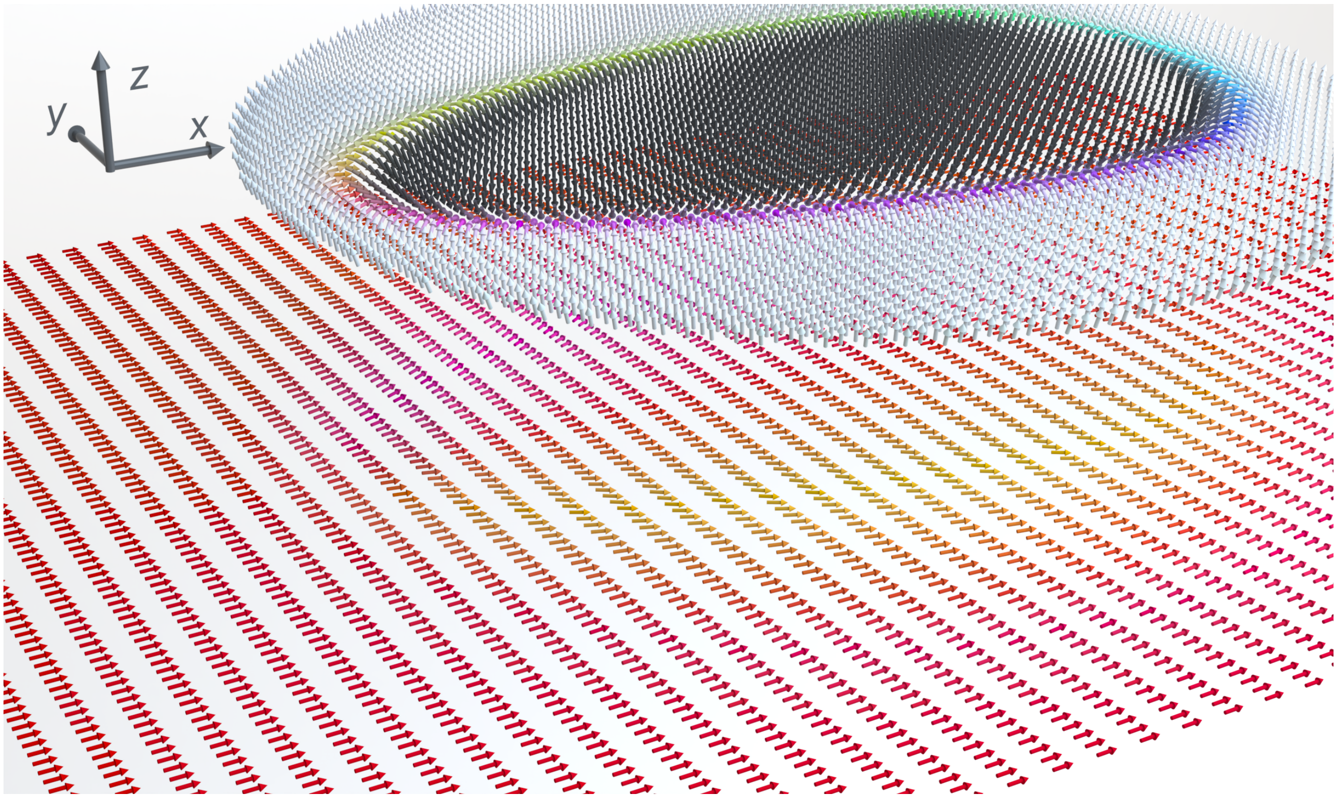

Figure S1: An artistic, high-resolution visualization of the simulated three-dimensional spatial distribution of the magnetic moments in nanodot and ferromagnetic stripe.

To demonstrate the spatial distribution of the magnetic texture magnetization of Néel-type nanodot and the imprint in the stripe, a simulated high-resolution magnetic 3D spatial distribution of the magnetisation texture is shown in Fig. S1.

Fig. S2 presets a simulated high-resolution magnetic 3D spatial distribution of the magnetization texture and $\mathbf{H}_{\mathrm{s-str}}(x,y,z = 6.5\ \mathrm{nm})$, the magnetostatic stray filed from the imprint. This stray field is opposite to and an order of magnitude lower than the field, which is created by the nanodot $\mathbf{H}_{\mathrm{s-dot}}$ S3.

To understand the effects of skyrmion core polarization, D sign, and stripe magnetization direction on skyrmion shape and size, we performed a series of simulations for $D = -1.6$ mJ/m^2 of hybrid nanostructure (see Fig. S4). Micromagnetic simulations showed that a horizontal change in the direction of magnetization orientation in the stripe changes the side of the narrower side of the skyrmion. Also an alteration in the skyrmion polarity in the stripe results in a horizontal mirror image of the skyrmion's magnetization texture in the nanodot.

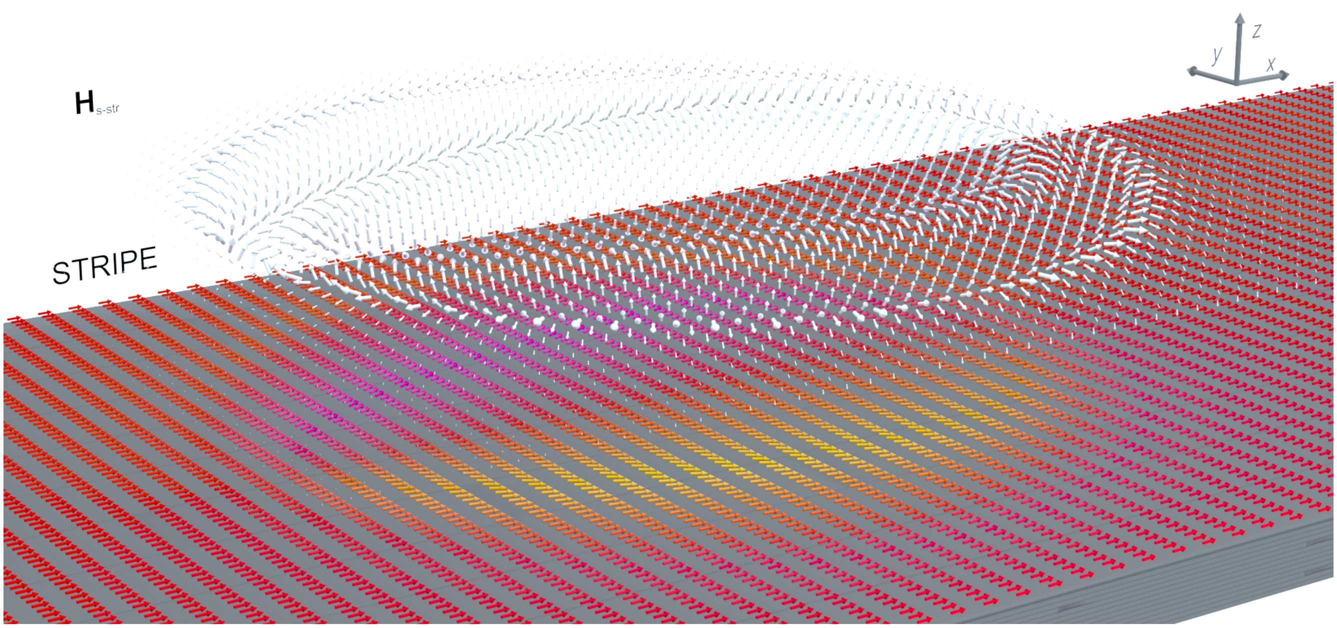

Figure S2: Magnetization in the Py stripe (colored arrows) and distribution of the stray magnetic field (gray arrows) generated solely by the imprint in the stripe, excluding the field from the nanodot. The size of the arrows is proportional to the magnetic field strength. The simulation performed with the freezing-spin technique with $D = -1.6$ mJ/m^2.

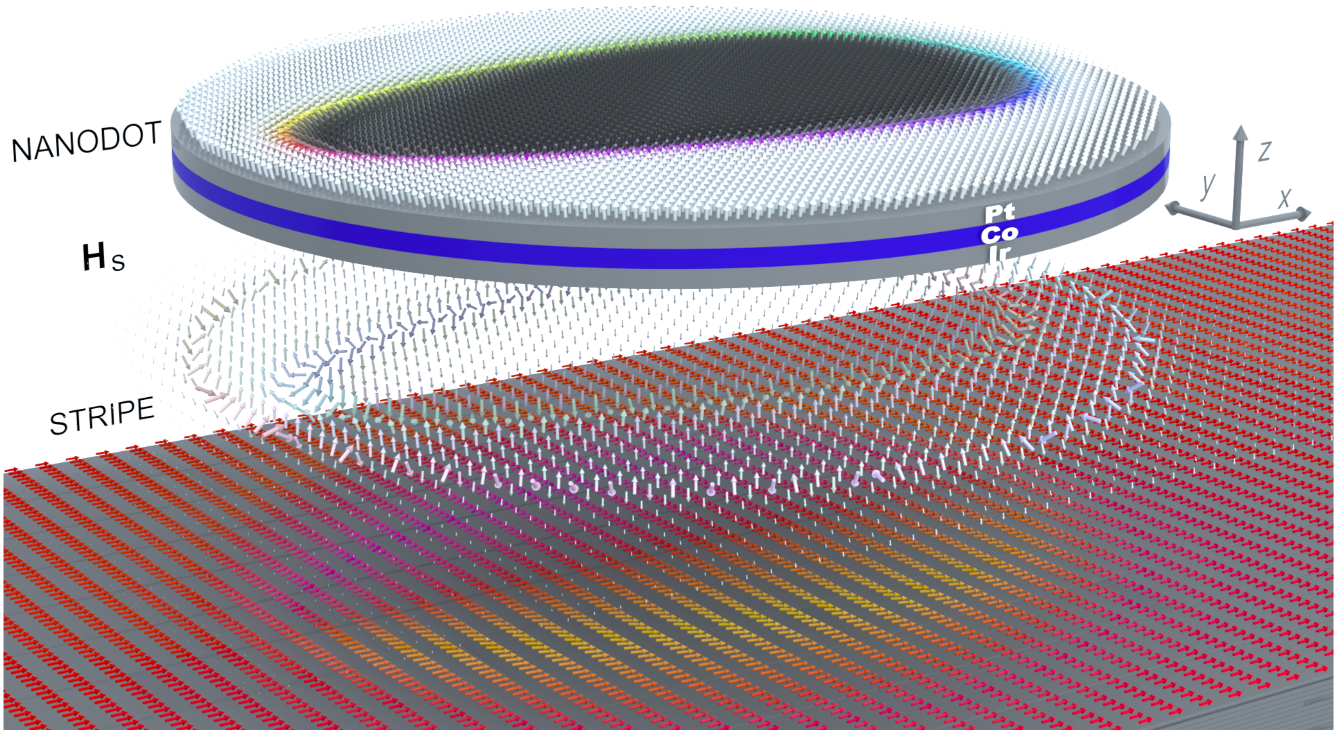

Figure S3: 3D plot of the magnetization texture and the stray magnetic field distribution in the investigated system for $D = -1.6$ mJ/m^2. The figure shows the spatial distribution of the magnetization in the nanodot (top), the magnetic field in the space between (middle), and the magnetization in the stripe (bottom). The color of the arrows in the stripe represents the direction of magnetization.

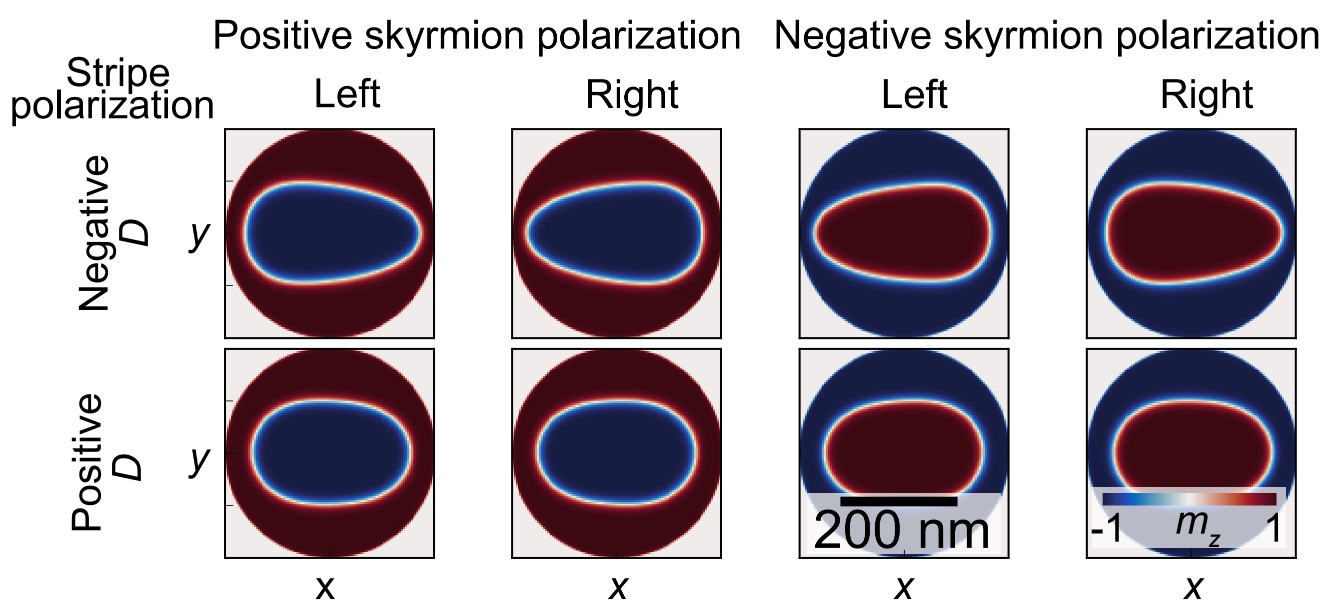

Figure S4: Static magnetization configuration in a Pt/Co/Ir nanodot with $D = \pm 1.6$ mJ/m^2 dipolarly coupled to the Py stripe. The color scale is given in reduced units of magnetization.